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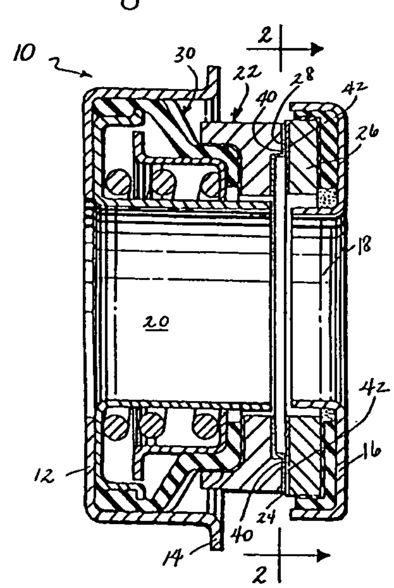
(54) Internal combustion engine coolant pump seal face.

(57) A strong, reliable face seal assembly for a mechanical seal, particularly a mechanical seal in a coolant pump of a heavy duty diesel internal combustion engine and method for forming such a seal are provided. The seal assembly includes rotating and stationary ring-shaped sealing elements on opposite sides of a sealing interface separated by a fluid film. Each of the ring-shaped sealing elements is formed from a substrate, preferably a ceramic, compatible with diamond and coated with a diamond film with a low coefficient of friction and a high thermal conductivity that is resistant to coolant solids adhesion so that the film extends beyond the sealing interface. A vapor deposition process is used to coat the diamond film on the compatible substrate.

Fig. 1



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Technical Field

The present invention is directed gen rally to seals for internal combustion engine coolant pumps and specifically to a hard, low friction, high thermal conductivity seal face for an internal combustion engine coolant pump and to a method for forming such a seal face.

Background of the Invention

Internal combustion engine coolant pumps typically include a mechanical face seal with at least one surface that rotates relative to a second surface that does not rotate, but is stationary. A fluid film of coolant or coolant vapor usually separates the seal surfaces and conducts heat away from the seal face interface to maintain the face temperature within an optimum operating range. When the face temperature exceeds the boiling point of the coolant flowing through the pump, deposits form and adhere to the seal face surfaces. The formation and adherence of these deposits to the seal face surfaces causes the faces to separate so that a tight seal cannot be formed. As a result, the coolant pump face seals leak.

The mechanical seal arrangement employed by most internal combustion engine coolant pumps creates a great deal of wear on the sealing faces. These faces, which are usually formed on the interfacing surfaces of a stationary ring element and a rotatable ring element, are subjected to wear-producing forces during pump operation. When the sealing faces become worn, the seal fails and the pump leaks. The use of a hard wear-resistant material, such as, for example, an alumina ceramic, to form the sealing faces reduces wear; however, such materials produce undesired friction between the faces. The heat generated by high friction reduces mechanical efficiency and subjects the sealing rings to wear and other damage.

The precipitation of coolant solids produced when the face temperatures exceed the coolant boiling point is exacerbated by the presence of the chemical coolant additives often used to enhance coolant performance. These solids show a tendency to adhere to and build up on the mechanical seal sealing faces and cause seal leakage and failure.

The prior art has addressed some of the problems which accompany face seal fittings and operation. For example, U.S. Patent No. 3,874,680 to Mustoe et al. discloses a mechanical face seal for an automotive engin water pump made of a ceramic material, preferably a sintered magnesia-alumina spinel. The seal rings can also be formed of another material, such as alumina ceramic, and faced with sintered magnesia-alumina, although this is stated not to provide any advantage beside cost saving. A water pump seal ring made as described in this patent may have some of th wear-resistance and low friction characteristics desired; however, the desired seal interface heat reduction characteristics may not be achieved.

U.S. Patent No. 5,129,688 to McGarvey discloses a torque-reducing conduit connection including a metal ring coated with a diamond material positioned in an annular groove. This arrangement is stated to facilitate the movement of the ring in the groove so that the conduit, which is intended to be used in pressurized systems in an ultra-clean environment, can be sealed with diminished torque. It is not suggested that the face seal separation problem caused by high face temperatures exceeding the coolant boiling temperature in an internal combustion engine coolant pump could be solved by such an arrangement.

U.S. Patent No. 3,969,451 to Floyd et al. discloses a mechanical seal useful for a rotating shaft water pump including cooperating sealing elements, one of which is composed of a filled graphitic matrix and the other of which is a ceramic material. This combination of materials does not provide the hardness, low friction or heat conductivity desired for a long lasting reliable seal. The rotary mechanical face seal formed of carbon disclosed in U.S. Patent No. 5,135,235 to Parma and the sintered silicon carbide mechanical seal disclosed in U.S. Patent No. 5,080,378 to Kagawa present similar disadvantages.

A need exists, therefore, for a durable, reliable face seal element for the mechanical seal assembly of an internal combustion engine coolant pump that is hard and resists wear, has a low coefficient of friction and has high heat conductivity and for a method for forming such a face seal element.

Summary of Invention

It is a primary object of the present invention, therefore, to overcome the disadvantages of the prior art and provide a durable, reliable face seal element for an internal combustion engine coolant pump that displays high hardness, low friction and high conductivity and to provide a method for forming this face seal element.

It is another object of the present invention to provide a face seal element for an internal combustion engine coolant pump that is resistant to the adhesion and build up of precipitated coolant solids on the seal face.

It is a further object of the present invention to provide a face seal element for an internal combustion engin coolant pump that is inherently stable and resistant to damage from precipitated coolant solids.

It is yet another object of the present invention to provide a face seal element for an internal combustion engine coolant pump which reduces the interface temperature between cooperating face seal elements in the coolant pump mechanical seal assembly and avoids heating the coolant to temperatures in excess of the coolant boiling temperature.

It is yet a further object of the present invention to provide a method for making an inherently stable, high hardness, high thermal conductivity, low friction face seal element for an internal combustion engine coolant pump.

The aforesaid objects are achieved by providing a face seal element for an internal-combustion engine coolant pump face seal element comprising a covalently bonded high hardness, high thermal conductivity, low friction film coated on a compatible substrate. The film is formed from diamond and is preferably applied to a silicon carbide, silicon nitride or like compatible ceramic substrate or to a compatible metal substrate. The face seal element is formed by providing a selected silicon carbide, silicon nitride or like substrate or a metal substrate configured to the shape required to form a face seal element for an internal combustion engine coolant pump and coating the substrate with a film of diamond by a chemical vapor deposition process. The diamond coated substrate may optionally be lapped and polished prior to installation in the coolant pump sealing assembly.

Other objects and advantages will be apparent from the following description, claims and drawings.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of an internal combustion engine coolant pump seal; and

Figure 2 is a sectional view of a seal ring taken along lines 2-2 of Figure 1.

Detailed Description of the Preferred Embodiments

The type of coolant pump typically employed in a liquid cooled, heavy duty diesel internal combustion engine has a face seal which prevents coolant from leaking out of the coolant system between the stationary housing of the pump and the rotating pump shaft. Ideally, such coolant pumps should operate for at least 482 000 km (300,000 mil) without failure, particularly when they are installed in large thruck engines. How ver, th available coolant pump face seals have h retofor not reliably withstood either the rotational torques encountered during pump operation or th corrosive action of chemicals contained in the coolant.

Referring to the drawings, Figure 1 is a sectional view of a type of fac seal 10 used in a heavy duty diesel internal combustion engine. The face seal 10 is positioned between the coolant pump body (not shown) and shaft (not shown). The face seal includes a tubular cap portion 12 with a radial flange 14 which functions as a stop when the face seal cap portion is pressed into a sealed fit with the pump body (not shown). The face seal 10 further includes an annular cup 16 which has a U-shaped cross-sectional configuration. The central opening 18 of the cup 16 is sized to be secured to the coolant pump shaft (not shown) by a press fit. The tubular cap portion 12 of the face seal 10 includes an axially extending central section 20, which is sized to extend around the coolant pump shaft (not shown) without engaging the shaft.

An annular seal ring 22 with a nose 24 that engages a seat washer 26 in the annular cup 16 does not rotate with the coolant pump shaft (not shown). A hydrodynamic film is formed between the adjoining surfaces of the seal ring 22 and the seat washer 26 at interface 28.

The seal ring 22 is supported on the tubular cap portion 12 by a bellows 30, which acts as a support for the seal ring 22 and also forms a seal between the seal ring 22 and the cap 12. The ring 22 is usually secured to the bellows 30 by a press fit and by a suitable adhesive. The cup 16, the seat washer 26, the outer periphery of the seal ring 22 and part of the surface of the bellows 30 are exposed to the coolant, coolant additives and other chemicals and debris in the coolant system.

The primary causes of face seal failure are the chemicals in the coolant and the rotational torques to which the seal is subjected during coolant pump operation. The rotational torques arise from the "stick-slip" characteristics of operation of this type of seal. The interface 28 between the opposing faces of the seat washer 26 and the seal ring 22 normally is separated by a hydraulic film positioned between these faces. When the film is present, the film lowers coefficient of friction between the seat washer and seal ring faces at interface 28. However, the coefficient of friction increases if even part of the film disappears, even for an instant. It is typical of the operation of such a seal that the film varies during coolant pump operation and that the interface 28 will frequently stick together momentarily and then slip as the seat washer 26 rotates relative to the seal ring 22. The rotational torque on the seal parts increases substantially during a stick period, and the seal ring 22 tends to turn with the washer 26 during the stick period. As the coefficient of friction increases, the temperature of the faces at interface 28 increases. If the temperature of the faces exceeds the boiling point of the coolant, coolant chemicals precipitate

on the faces of the ring 22 and washer 26. This increases the width of the interface 28 and prevents the formation of a proper seal. The present invention avoids undesirable temperature increase at interface 28.

The dynamic torque on the seal ring 22 also can be minimized by the face seal of the present invention. The dynamic torque is the sum of the steady torque and the varying torque which arises from the alternate stick-slip contact between the ring 22 and the washer 26. One of the solutions proposed to reduce face seal failure due to rotational torque problems was to make both the seat washer 26 and the seal ring 22 of the same material, preferably silicon carbide, so that both components would have the same hardness. While this minimized the dynamic torque on the ring 22, the formation of deposits from the coolant and the adherence of these deposits to the seal faces when the seal face temperatures exceeded the coolant boiling point was still a problem. The present invention has solved both the problem of excess dynamic torque and the problem of face seal failure resulting from deposit formation.

The coolant pump face seal of the present invention is similar in construction to that described in U.S. Patent No. 4,275,889, issued June 30, 1981, which is also owned by the assignee of the present invention. The disclosure of U.S. Patent No. 4,275,889 is hereby incorporated herein by reference.

The present invention provides a high hardness, covalently bonded, high thermal conductivity seal face surface for heavy duty internal combustion engine coolant pumps. A heat conduction path is provided to conduct heat away from the seal face interface, which reduces the interface temperature so that the coolant is not heated above its boiling point. The present invention also provides a very hard non-reactive surface. This surface is inherently stable and resistant to damage by solids precipitated from the coolant. It is further resistant to adhesion and to the build up of precipitated solids.

Figure 2 illustrates the face seal of the present invention in a sectional view taken along line 2-2 of Figure 1. This view clearly illustrates the annular configurations of the seat washer 26, the seal ring 22 and the cup 16. The area of engagement of the interface 28 is shown by the cross-hatched area. As will be described in detail hereinbelow, at interface 28 each of the seat washer 26 and the seal ring 22 has a diamond coating. Additionally, the radial dimension of the interface is selected to provide maximum reduction in dynamic torque during boundary lubrication conditions.

The surfaces of seal ring 22 and seat washer 28 are each coated with a diamond film or coating at 40 and 42, respectively. The diamond films 40 and 42 extend beyond the interface 28 of the seal ring 22 and the seat washer 26 to provid a heat conduction path away from the interface 28. The high thermal conductivity of the diamond film lowers the temperature rise that would otherwise occur at interface 28, which substantially reduces the likelihood that the temperature of the interfacing surfaces of the seal ring 22 and the seat washer 26 will exceed the boiling point of the coolant.

The extremely high hardness of the diamond coatings 40 and 42 (10 on the Mohs scale) provided on the seal ring 22 and seat washer 28, respectively, make these surfaces resistant to the scoring and abrasion produced by solid contaminants or precipitated coolant chemicals on surfaces of lesser hardness. Moreover, the covalent bonding of the carbon atoms in the diamond structure of the coating minimizes the adherence of coolant solids to the faces of the seal ring 22 and the seat washer 28. Face separation caused by the formation and deposit of undesirable solids at the seal interface 28 should not occur with the face seal design of the present invention.

The highly reliable coolant pump seals of the present invention are formed by forming a seal ring element and a seat washer element which are correspondingly configured to produce a reliable, fluid tight seal in an internal combustion engine fuel pump. The seal ring element and the seat washer element are each formed from a suitable substrate material that is both compatible with diamond and is itself hard and wear-resistant. Preferred for this purpose are ceramics such as silicon carbide and silicon nitride. However, other substrates with a similar hardness that are compatible with diamond so that a diamond film or coating may be applied to the substrate surface to produce a reliable, fluid-tight seal under the conditions typically encountered in an internal combustion engine coolant pump would also be suitable. Compatible metals, such as, for example, stainless steel can also be used to form a substrate for the diamond coating.

The diamond film is applied to the selected substrate by a chemical vapor deposition process or, in the case of a compatible metal substrate, by a physical vapor deposition process. The seal ring element and the seat washer element may be used as coated with the diamond film. Alternatively, the diamond coated elements may be lapped and polished before their installation in the coolant pump seal. The diamond film is applied to a maximum thickness that is less than 200 μm, and preferably less than 50 μm, with a hardn ss greater than 2500 on the Vickers hardness scale and a thermal conductivity greater than 85 w/m•k at 25 C (room temperature).

The measured friction coefficients for the diamond film seal faces 40 and 42 at interfac 28 are less than 0.10 when the interface is lubricated and less than 0.15 when the interface is dry. A silicon carbide face and an opposed hard carbon graphite face at an interface like the interface 28 in a seal currently in use has a lubricated coefficient of friction of 0.10 and a dry coefficient of friction of 0.12. Two opposing silicon carbide faces at an interface like the interface 28 have a lubricated coefficient of friction of 0.12 and a dry coefficient of friction 0.20.

Tests have been conducted to determine the reliability and longevity of the diamond-face seal of the present invention. A test coolant pump with a seal having a seal ring coated with a diamond film and a seat washer, also coated with a diamond film was set up to run under simulated engine operating conditions. The coolant supplemental additive concentration was initially at the recommended level and was increased in increments of one recommended level every 150 to 200 h until a final concentration of five times the recommended level was reached. After operating for a total of 850 h, the diamond face seal showed no leakage, even with the increased coolant chemical concentration. There was also no formation of coolant deposits on the diamond seal surfaces. In this same test, a coolant pump with a seal having silicon carbide and hard carbon graphite seal faces, currently in use, forms adherent coolant deposits and leaks coolant in 200 to 400 h with the coolant at a concentration of two to three times the recommended level.

A coolant pump face seal made in accordance with the present invention provides a durable, reliable, fluid-tight seal capable of functioning for extended periods without failure under the adverse operating conditions encountered in a heavy duty diesel internal combustion engine.

Industrial Applicability

The seal structure of the present invention will find its primary applicability in the formation of reliable fluid-tight face seals for coolant pumps for heavy duty diesel internal combustion engines. However, this seal structure could also be used to form a strong, reliable seal in any similar mechanical seal wherein one sealing ring element separated by a fluid film rotates relative to a stationary ring element.

Claims

1. A seal assembly for an internal combustion engin coolant pump mechanical seal which operates to pump coolant through said pump by one ring element rotating over a second, stationary ring element separated from said one ring element by a film of coolant, wherein said seal assembly includ s annular seat washer means in said one ring element for rotating when the pump is in operation, sealing ring means in said second ring element for remaining stationary when the pump is in operation, and interface means between the seat washer means and the sealing ring means for holding a film of coolant between said seat washer means and said sealing ring means to form a fluid-tight seal, wherein each of said seat washer means and said sealing ring means comprises a compatible substrate coated on a surface at said interface means with a thin film of diamond.

2. The seal assembly described in claim 1, wherein said substrate is a hard, wear-resistant ceramic, and, preferably, wherein said ceramic is selected from the group consisting of silicon carbide and silicon nitride.

3. The seal assembly described in claim 1 or 2, wherein the lubricated coefficient of friction at said interface means is less than 0.10 and/or wherein the dry coefficient of friction at said interface means is less than 0.15.

4. The seal assembly described in any preceding claim, wherein said thin film of diamond is less than 200 µm thick, preferably less than 50 µm thick.

5. The seal assembly described in any preceding, wherein said substrate is a metal, preferably stainless steel.

6. The seal assembly described in any preceding claim, wherein said thin film of diamond has a hardness greater than 2500 on the Vickers hardness scale.

7. The seal assembly described in any preceding claim, wherein said thin film of diamond has a thermal conductivity greater than 85 w/m•k at 25 C.

8. A method of forming a seal assembly for an internal combustion engine coolant pump mechanical seal which operates to pump coolant through said pump by one ring element rotating over a second, stationary ring element s parated from said one ring element at an interface by a film of coolant, wherein said method includes the steps of:

a) forming a washer element configured to cooperate with said one ring element from a selected ceramic substrate compatible with diamond;

b) forming a sealing ring element configured to fit on said stationary ring element from a selected substrate compatible with diamond; and

c) applying a thin film of diamond to the surfaces of each of said washer element and said sealing ring element in the areas at and adjacent to said interface by a vapor deposition process selected from the group consisting of chemical and physical vapor deposition processes.

9. The method described in claim 8, wherein said substrate is selected from the group consisting of silicon carbide ceramics, silicon nitride ceramics and metals compatible with diamond.

10. The method described in claim 8 or 9, wherein, preferably for a substrate selected from the group consisting of silicon carbide ceramics and silicon nitride ceramics, said diamond film is applied by said chemical vapor deposition process to a thickness of less than 200 µm, preferably for a metal compatible with diamond as a substrate, said diamond film is applied to said substrate by a physical vapor deposition process to a thickness less than 200 µm, and/or wherein said diamond film applied by said vapor deposition process has a Vickers hardness greater than 2500 and a thermal conductivity greater than 85 w/m•k at 25 C.

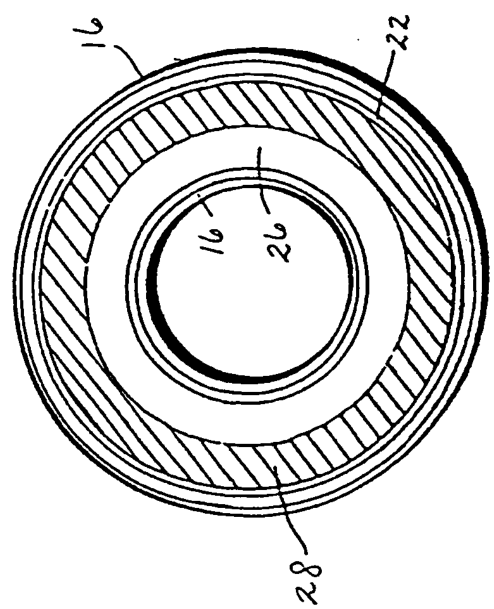

Fig. 2

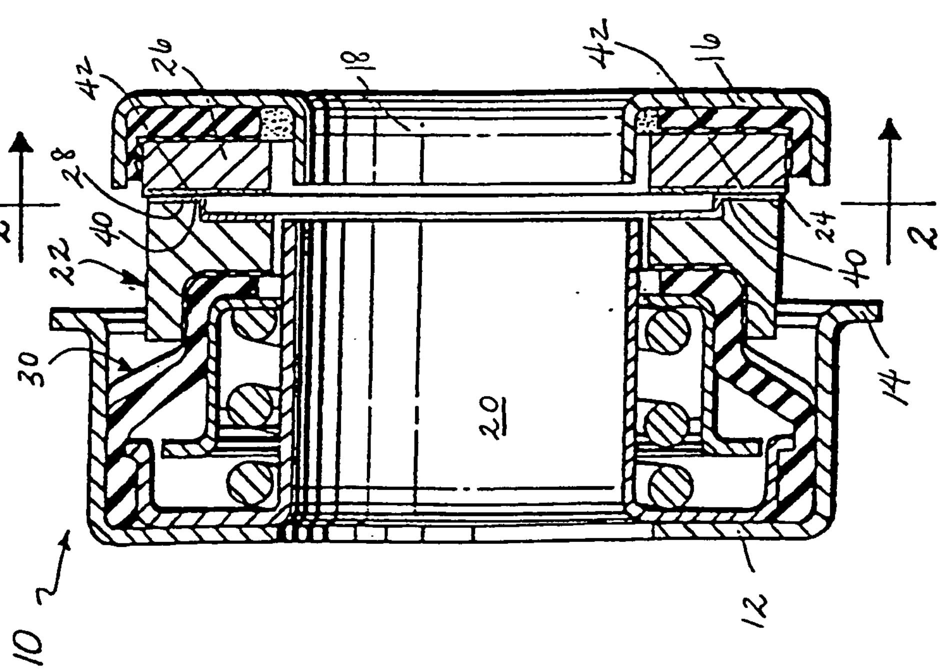

Fig. 1

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 10 0933

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP-A-0 351 554 (F. BURGMANN) * column 2, line 45 - column 3, line 9; figures * ---	1,4	F16J15/34
A	DE-A-43 02 407 (NGK) * abstract * ---	1,2,8-10	
A	EP-A-0 435 272 (NGK) * abstract * ---	1,2,8-10	
A,D	US-A-4 275 889 (BUTLER ET AL.) * abstract; examples * -----	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
F16J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 July 1995	Narminio, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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